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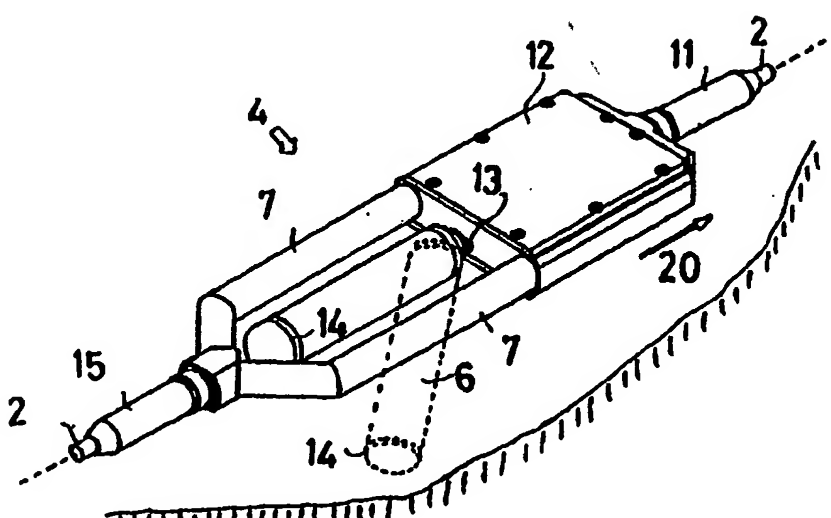
In English translation (filed in Norwegian).

(54) Title: A METHOD FOR UNDERTAKING MARINE, SEISMIC MEASUREMENTS, AS WELL AS A SEISMIC SEA-BED CABLE FOR CARRYING OUT SAID METHOD



(57) Abstract

A method for carrying out marine seismic surveys by using a seismic cable comprising a cable (2) and sensors (4) for detecting seismic signals, said sensors (4) comprising geophone units (6) which rest in the measuring positions on the ocean floor during measurement of the seismic signals and where the seismic cable is moved along the seabed to its next measuring position between the measurements. Before measurements are taken the geophone units (6) are subjected to vibrations so that the geophone units (6) assume a position in good contact with the ocean floor (3) and dig themselves down into it. The invention also comprises a seismic cable for carrying out the method. Here the geophone units (6) are loosely attached within the frame structure (7) and are equipped with at least one vibrator (14) which is powered via the cable (2).

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A Method for Undertaking Marine, Seismic Measurements, as well as a Seismic Sea-Bed Cable for Carrying out Said Method.

The present invention relates to a method for performing marine seismic surveys by using a cable arranged on the sea bed and comprising geophone units and, the invention relates, moreover, to such a cable adapted for carrying out the stated method.

To use such cables on the sea bed in the performance of seismic surveys in a marine environment is previously known. In this connection, reference is made to Norwegian printed specification No. 168,610 and US patent No. 4,870,625.

From the above publications it is previously known to use a cable which at the time of survey rests on the ocean floor. Such a cable may be provided with geophones as well as hydrophones and, thus, can record both pressure and shear waves that originate from the seismic signals to be detected. A closer description of the survey conditions is given, inter alia, in the two above references.

In practice it has proved to be difficult to obtain a sufficiently good and stable mechanical connection between the geophones and the sea bed while the survey takes place. This may lead to somewhat indefinite detection, in particular of the shear waves that form part of the seismic signals.

The object of the present invention is to provide a method that leads to a more precise recording of the seismic signals than was previously the case, without increasing time consumption during the survey. Further, the object is to provide a simple and efficient cable for the performance of such a method and at the same time avoiding the drawbacks of previously known techniques.

This is obtained by using a method and a cable on the sea bed in accordance with the appended patent claims.

In order to give a more clear understanding of the present invention, reference is made to the description of the working examples detailed below, as well to as the accompanying drawings, in which:

Fig. 1 is a perspective view of how a cable can be disposed on the seabed, for instance by means of a submarine vessel 1,

Fig. 2 shows a schematic view of a sensor which can be used in connection with a seabed cable according to Fig. 1,

Fig. 3 shows a sensor according to Fig. 2, but here shown in perspective view, and

Fig. 4 shows more in detail the construction of the geophone unit which forms part of a sensor.

It is pointed out that the same reference numerals are used in all the figures of drawings, to the extent that this is found serviceable; that the figures have not been drawn to true scale and that the figures show simplified embodiments of the invention, said simplifications having been carried out in order that the principle of the invention shall be illustrated in as simple a manner as possible. Finally, it is pointed out that the drawings only show one possible embodiment of the invention, which means that many other embodiments may be contemplated without going beyond the scope of the invention.

Fig. 1 showns how a submarine vessel 1 can tow a cable on the seabed 3. It may be noted that the handling of the cable is, per se, previously known and lies outside the scope of the present invention. Details of such handling are therefore not mentioned here, except that the submarine vessel 1 can be equipped with a seismic source 9. However, the seismic signals can also be generated by separate source-s. Likewise, a surface vessel can be used instead of a submarine vessel.

Along the cable 2 itself, which forms part of the cable, sensors 4 are provided which can comprise both geophones and hydrophones. The distribution of the sensors 4 can be regular or irregular along the cable 2, and the cable 2 normally has an extra weight at the end in the form of, for instance, an attached, drag chain 5 which helps to keep the entire length of the cable stretched out. It can also be noted that several such cables can be used in parallell on the sea bed and can then, for instance, be attached to a common transverse pull bar (not shown), which keeps the cables at a constant distance from each other during tansport. As a typical

example the cable can have a length of 1-2 km and be equipped with approximately 100 sensors 4 at intervals of about 10 m.

Under the vessel the cable may well be equipped with a termination box that may contain various electronic circuitry for data transmission. The cable 2 itself must be dimensioned to withstand pressure, cable weight and forces acting during towing. It can advantageously be reinforced with wire of Kevlar or similar materials that endure strong mechanical stress.

The present invention relates in particular to the conditions prevailing during surveys, that is, while the cable lies immobile on the ocean floor. The survey is carried out while the cable lies at rest and when the survey is finished the cable is moved to the next measuring position.

The problem of previously known cables on the sea bed has been that the geophone units, which can either constitute the entire sensor 4 or only a part thereof, does not get sufficiently good and reproducible contact with the sea bed 3 during the survey process. As a consequence the measurement, in particular of seismic shear waves, can be somewhat uncertain, so that the result of such a survey can be misinterpreted.

Fig. 2 showns how the geophone unit 6 is attached to the cable 2. The cable is here seen from above.

The cable 2 contains elements for the transmission of mechanical tension, energy transmission, for instance in the form of electric power, and necessary signal transmission via the cable itself. The cable 2 is next connected to the sensor 4 by means of an intermediate connector 11. The sensor 4, as shown here, consists of two main parts, where the first one is a pressure container 12 for the hydrophone unit. The hydrophone may well be located separately in the box 12 and is protected from the environment. It is adapted to record and later remove reflected signals from the surface. This pressure container 12 can further contain an A/D converter, as well as the necessary processing equipment, for instance including a microprocessor and the necessary memory means.

The second part of the sensor 4 comprises the geophone unit 6 with its flexible connections that may be mechanical, electrical or even hydraulic or pneumatic. It is an advantage that the specific weight of the geophone corresponds to the greatest possible extent to the specific weight of the material of the sea bed (specific gravity approximately 1.7). Moreover, the geophone unit can contain a data unit for signal digitalization and signal amplification. The data unit can also pre-process the data to a certain extent.

It must further be mentioned that the elements that form part of the cable 2 are split into two parts which run internally in a symmetrically arranged frame structure 7 which surrounds both the pressure container 12 and the geophone unit 6. The cable 2 is preferably equipped with branches within the frame structure 7 for the necessary connections to the hydrophone unit in the pressure container 12 as well as to the geophone unit 6. Further the cable 2 continues to the right through a new connector 15 and further leads via the next cable section 2 to the next sensor which preferably is of the same type as the one illustrated here, but which can also be of a somewhat different type.

The most important feature of the present invention is, in addition to the frame structure 7 and its protective envelopment of the cable and the screening of the recording and sensitive elements of the sensor unit, the design of the geophone unit 6 itself.

As appears from Figs. 2, 3 and 4 the geophone unit 6 is shaped as an elongated, cylindrical unit. It is only attached to the cable 2 via a pressure container 12 and a frame structure 7 by means of flexible joints 8, 9, 10 of different types, all preferably located at the same end of the geophone unit. The figure showns a connector 8, a flexible group of cables 9 and a combined cap and connector 10 which leads to the active parts of the geophone unit 6. Altogether this connection can be mechanically ensured by a flexible suspension 13 and the construction of all these components must of course be adapted to the cable construction in question, and the actual construction of the geophone unit. The most important condition is that there is a flexible connection

which allows the geophone unit 6 to move, within certain limitations, in all co-ordinate directions in relation to the frame structure 7. Thus, the suspension does not obstruct movement in direction X, Y or Z, nor does it obstruct a limited rotation of the geophone unit 6. If all the connection joints 8, 9, 10, 13 are located close to each other at one end of the geophone unit 6, the geophone is also allowed to tilt transversely to the axis of the frame structure and the cable.

When the cable with its sensors is towed along the ocean floor, this is done in the direction of the arrow 20 as shown in the figure. When the cable 2 lies at rest the geophone unit 6 will also lie at rest within the frame structure 7, however the purely local positioning of the geophone unit on the ocean floor will depend on the topography of the immediate location. It may well happen, therefore, that the geophone unit 6 assumes an unstable position on a stone or the like, or the geophone unit 6 may lie on a soft, organic material which gives a poor mechanical connection between the geophone unit and the ocean floor 3 beneath.

In order that the geophone unit 6 shall have best possible mechanical contact with the sea bed 3 a vibrator 14 is provided at the free end of the geophone unit 6. As soon as the cable 2 is put to rest on the ocean floor 3, the vibrator 14, being powered through the cable 2, is put into operation which in part will result in geophone unit 6 being shaken into a suitable position on the ocean floor 3 and in part result in the geophone unit's 6 more or less sinking down into the ocean floor 3. This is of course dependent on the general character of the ocean floor, but nevertheless the mechanical connection between the geophone unit 6 and the ocena floor 3 will be substantially stronger than in previous solutions.

The vibrator 14 which preferably is located at the free end of the geophone unit 6 can be constructed in many ways and can be powered by different means. In a preferred embodiment best shown in Fig. 4, the vibrator 14 comprises an electrically or hydraulically run rotating motor 16 which is equipped with an eccentric balance wheel with an assymmetric

weight 17. If the motor is electric, it should be surrounded by magnetic screening 24 in order not to influence the compass, and should moreover be located at a distance as far as possible from it. The balance wheel is enclosed in the geophone unit itself. When the eccentric balance wheel rotates at great speed, this will entail that the free end of the geophone unit 6 will seek to move rapidly with small circular movements. It is therefore an advantage that the eccentric balance wheel is located at the part of the geophone unit 6 which has the greatest freedom of movement. If the environment is not too rigid the particles near the geophone unit 6 will be pushed aside and the geophone unit 6 will bury itself in mud and particles on the floor 3, and form good mechanical connection with it, so that the seismic signals in the form of shear waves which move through, and partly are reflected by, supporting formations, will be transferred to the three geophones 21, 22, 23 which are located inside the geophone unit 6, after the balance wheel with its mechanical eccentricity 17 has stopped, so that the vibrations have ceased and the geophone unit 6 has stationed itself in the survey position.

Advantageously, the vibrator 14 can be maintained in the correct position against the interior of the housing, for instance by means of a shoulder 25.

The design of the geophone itself and the recording of data have not been stated more closely, since known techniques are used here.

In Fig. 3 the burying of the geophone unit 6 due to the vibration is shown in more detail as the sensor 4 is shown in a perspective view. The dotted lines show which position that the geophone unit 6 can assume after the vibration phase is ended and the survey is to begin. Since the geophone unit 6 preferably contains three geophones 21, 22, 23 that record signals in three ortogonal directions, as well as a three dimensional compass 18 and inclinometer 19, the received signals can be associated with a determined reference network of co-ordinates and give unambiguous signals no matter which position and orientation each individual geophone unit 6 adopts in space. Likewise the attachment via the flexible

suspension 13, as well as the cylindrical surface of the geophone unit, will mean that the geophone unit 6 is easily towed away when the cable, after the concluded survey, is towed in the direction indicated by the arrow 20.

Many different modifications of the present invention can be contemplated. Thus, the vibrator 14 can be designed in other ways than described above. It may for instance be designed as a linear piston which is moved back and forth and thereby vibrates the geophone unit in one plane only. If such a linear piston is located in the same direction as the axis of the geophone unit, the vibration can also be executed in the axial direction. A combination of several different vibration generators is also comprised by the scope of the present invention. An unbalanced rotation motor as shown in Fig. 4 can also be equipped with, for instance, an arrangement which yields abrupt, axial stroke movements similar to the arrangement in a percussion drill. Likewise it must be pointed out that the vibrators can be driven both electrically, hydraulically and/or pneumatically. The geophone unit 6 is preferably designed in such a manner that it obtains approximately the same specific weight as the material on the ocean floor, most often about 1.7 or in any case between 1.5 and 2.0. Likewise the mass in the vibrator itself can constitute a relatively large portion, for instance up to about 10% of the mass of the geophone unit, so that sufficient force is obtained during vibration. Likewise the choice of material for the geophone unit 6 can be of a certain importance for the ability of the unit to dig itself down into the sea bed 3. It is however preferred that the geophone unit 6 has a rough or even uneven surface, so that when it has obtained good mechanical contact with the particles in the environment it no longer moves easily in relation to these. The orientation of the geophone unit after ended vibration can be detected by the inclinometer and the compass.

The frequency at which the vibrator operates can vary within wide limits. As an example it can be mentioned that the frequency can lie between 50 and 150 Hz. However, lower frequencies can also be contemplated. In particular environmental conditions some specific frequencies can be advan-

tageous. Further, it can be mentioned that the frequency can vary in a controlled manner. When a vibrator with rotating eccentricity is used, the vibrator can thus be started with a low but increasing rotational speed and be maintained at maximum r.p.m. for a predetermined period before the rotational speed is reduced again before it stops. Any progression of the vibrational frequency thus lies within the scope of the present invention.

The geophone unit can also be equipped with more than one vibrator and the different vibrators can vibrate on different planes and/or along different axes and vibrate at different or similar frequencies and amplitudes.

It shall be noted that the cable on the sea bed can also with advantage comprise hydrophone units which then can with advantage be placed in the pressure container 12. The pressure container 12 can also contain a data unit for signal digitalization and signal amplification. Such a data unit can also process the acquired data and intermediately store them and/or transmit them. The frame structure 7 can consist of metal and can be welded to the pressure container 12 so that the cable elements from the cable 2 can be divided in two groups each passing through its own side of the frame structure and having branches leading into the pressure container 12 to be connected by the suitable connections to the compass 18, the inclinometer 19, the geophones 21, 22 and 23 as well as the motor 16. If the sea bed cable is equipped with a hydrophone, this must also be connected to the correct elements in the cable. This connection is then preferably established directly via the connector 11. Finally, the geophone unit can have other geometrical shapes, the cross-section may for instance be oval or polygonal.

Claims

1. A method for carrying out marine seismic measurements by using a sea bed cable comprising a cable (2) and sensors (4) for detecting seismic signals, said sensors (4) comprising geophone units (6) which rest in the measuring positions on the ocean floor during measurement of the seismic signals and where the sea bed cable is moved along the sea bed (3) to its next measuring position between the measurements, c h a r a c t e r i z e d i n that the geophone units (6), before the measurements are started, are subjected to vibrations so that they assume rest positions in good contact with the ocean floor (3).

2. A method according to claim 1, c h a r a c t e r i z e d i n that the vibrations the geophone units (6) are subjected to take place in at least one plane and/or along at least one direction of axis and have a variable and controllable frequency.

3. A method according to claim 1 or 2, and where the geophone unit (6) is a substantially elongated, cylindrical unit which is free and unconnected at one end, c h a r a c t e r i z e d i n that the vibrations in each case are generated substantially at the free end of the geophone unit (6).

4. A seismic cable to be used on the sea bed and comprising locally disposed sensors (4) placed at intervals along a cable (2), said sensors (4) comprising geophone units (6) adapted to be situated on the ocean floor while seismic signals are detected, c h a r a c t e r i z e d i n that the geophone unit (6) is movably disposed within a surrounding symmetrical frame structure (7) containing through passages for said cable (2).

5. A seismic cable according to claim 4, c h a r a c t e r i z e d i n that the geophone unit (6) is connected to the cable (2) which is located inside the frame

structure (7) via at least one flexible connection (9,13) disposed at one end of the geophone unit (6), and that the cable (2) passes through the frame structure (7) to the next, succeeding sensor (4) in the series of sensors (4) along said cable (2).

6. A seismic cable according to claim 4 or 5, characterized in that the geophone unit (6) which preferably has approximately the same specific weight as the mass on the ocean floor, is suspended centrally in the frame structure (7) at the end where the flexible connection (9,13) with the cable (2) is located, while the opposite end of the geophone unit (6) is completely free without any connection with the frame structure (7) or said cable (2).

7. A seismic cable according to one of claims 4-6, characterized in that the geophone unit (6) is an elongated, cylindrical member which at its first end is equipped with the flexible connection (9,13) to the frame structure (7), at its middle section (16) is equipped with geophones, compass and inclinometer, and at its second free or distal end is equipped with at least one vibrator (14) adapted to apply the vibrations to the geophone unit (6) in at least one plane and/or along at least one axis.

8. A seismic cable according to claim 7, characterized in that the vibrator(s) (14) comprise(s) at least a rotating and/or resiprocating motor (16) with an asymmetric weight (17), said motor being powered via the flexible connection (9,13) by the cable (2).

9. A seismic cable according to one of claims 7-8 characterized in that the vibrator (14) is electrically powered.

10. A seismic cable according to one of claims 7-8, characterized in that the vibrator (14) is hydraulically or pneumatically powered.

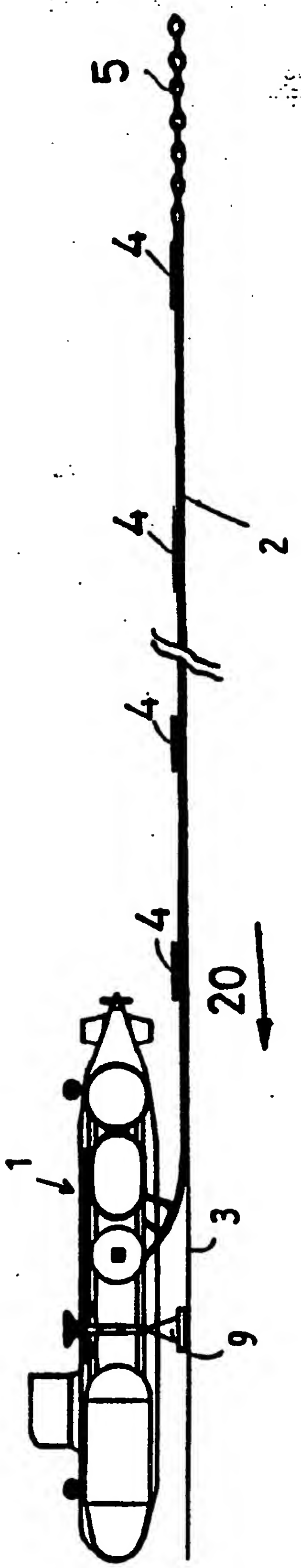


FIG. 1

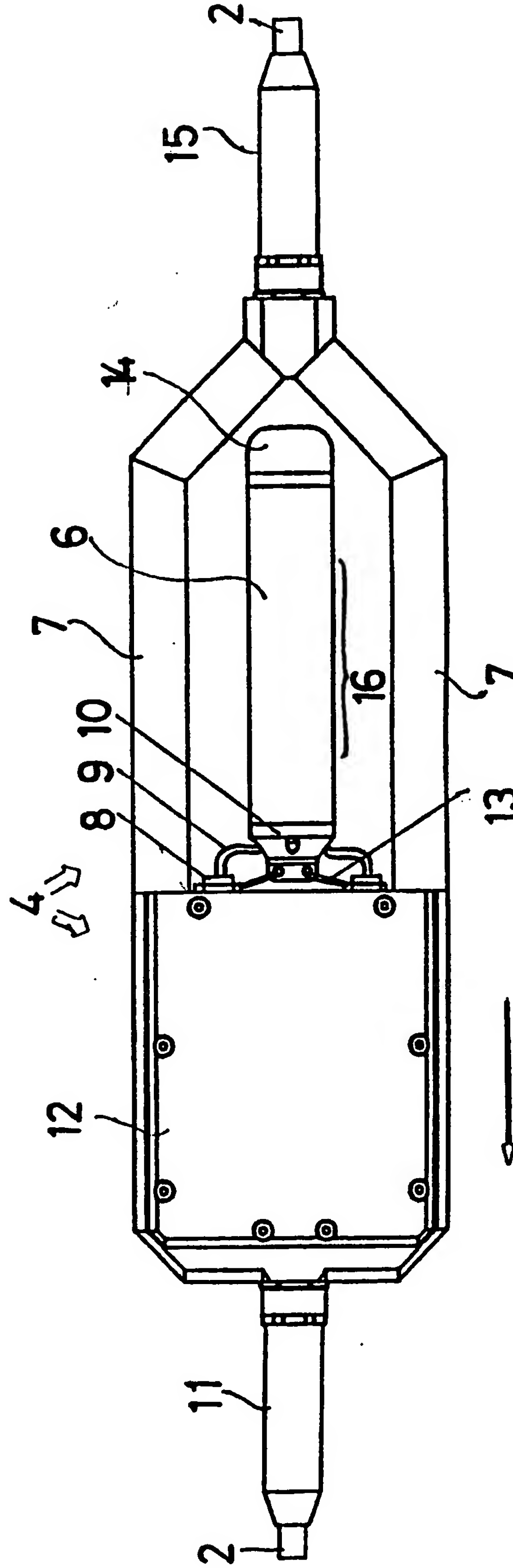
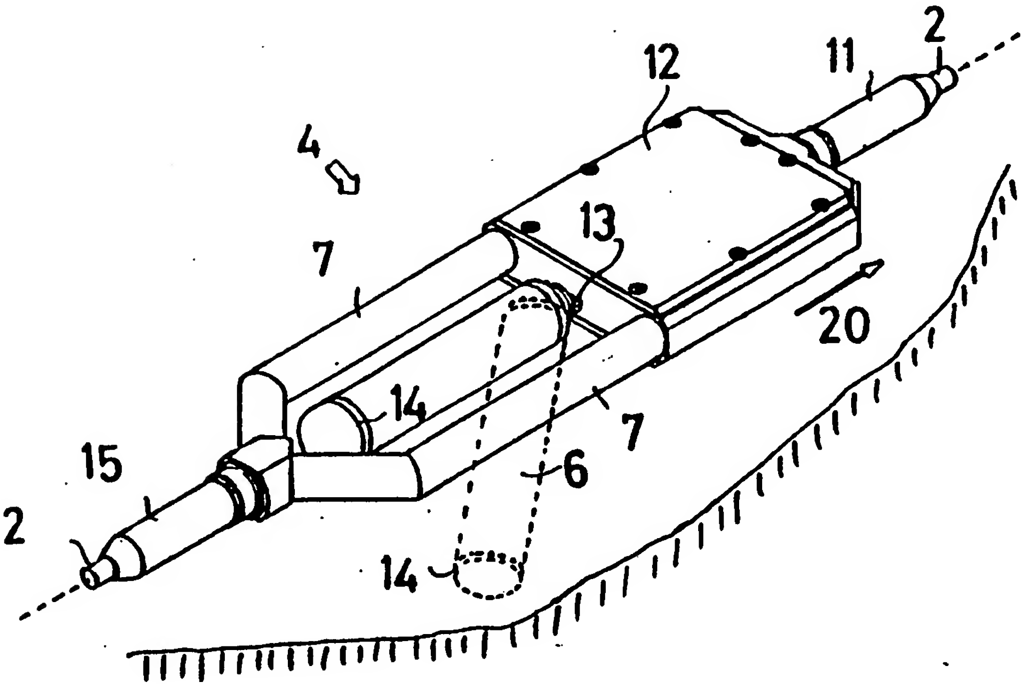
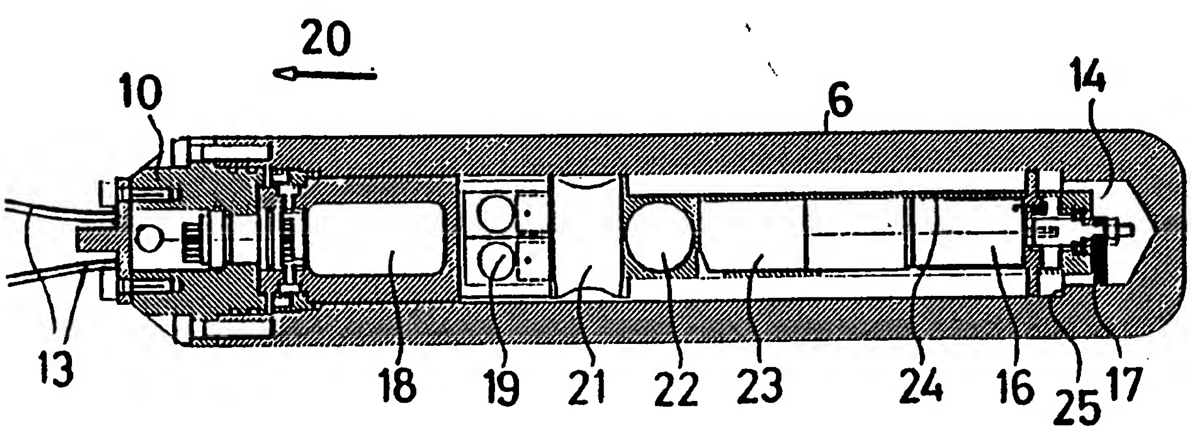


FIG. 2



F I G. 3



F I G. 4

INTERNATIONAL SEARCH REPORT

International application No.
PC[illegible] 94/00043

A. CLASSIFICATION OF SUBJECT MATTER

IPC : G01V 1/20, G01V 1/38
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC : G01V

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

DIALOG, CLAIMS, WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	DE, A, 2220650 (WESTERN GEOPHYSICAL CO.), 15 March 1973 (15.03.73), page 21, line 1 - line 13 --	4-6
A	WO, A1, 9219991 (SVENNING BJORNAR ET AL.), 12 November 1992 (12.11.92), page 4, line 29 - line 37 --	7
A	Derwent's abstract, No 91-279274/38, week 9138, ABSTRACT OF SU, 1601595 (NEFTEGEOFIZIKA COMB), 23 October 1990 (23.10.90) --	

[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be of particular relevance
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- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
16 June 1994	20 -06- 1994

Name and mailing address of the ISA/	Authorized officer
Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Stefan Svahn Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT[redacted]94/00043

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US, A, 4870625 (DEWEY R. YOUNG), 26 Sept 1989 (26.09.89), cited in the application --	
A	WO, A1, 9106877 (SVENNING BJORNAR ET AL.), 16 May 1991 (16.05.91) -- --------	

INTERNATIONAL SEARCH REPORT

International application No.
PCT/NO 94/00043

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. [ ] Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. [ ] Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. [ ] Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

See the attached sheet.

1. [ ] As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. [X] As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. [ ] As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. [ ] No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest
[ ] The additional search fees were accompanied by the applicant's protest.
[ ] No protest accompanied the payment of additional search fees.

I: Claims 1-3 and 7-10 define one invention, relating to a method of marine seismic surveying and a marine seismic seabed cable respectively. The method includes vibrating of geophone units contained in a marine seismic seabed cable, and the cable includes a geophone unit containing a vibrator..

II: Claims 4-6 define one invention relating to a seismic seabed cable containing flexibly mounted geophone units.

The "special technical features" of group I relate to vibration of geophone units in a marine seismic seabed cable, while the "special technical features" of group II relate to flexible geophone units in a marine seismic seabed cable. There is no technical relationship among these inventions involving one or more of the same or corresponding technical features. Thus, these groups of inventions are not so linked as to form a single general inventive concept (Rule13.1).

INTERNATIONAL SEARCH REPORT

Information on patent family members

28/05/94

International application No.
PCT/[illegible] 94/00043

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
DE-A- 2220650	15/03/73	AU-B- 466273	23/10/75
		AU-A- 4179472	08/11/73
		CA-A- 980455	23/12/75
		FR-A,B- 2135225	15/12/72
		GB-A- 1385971	05/03/75
		US-A- 3825886	23/07/74
		US-A- 3921755	25/11/75
WO-A1- 9219991	12/11/92	AU-A- 1982792	21/12/92
US-A- 4870625	26/09/89	NONE	
WO-A1- 9106877	16/05/91	AU-A- 6534290	31/05/91
		EP-A- 0497814	12/08/92